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Trace Metal Retention When Firing Hazardous Waste in a Fluidized-Bed Incinerator

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Trace Metal Retention When Firing Hazardous Waste in a Fluidized-Bed Incinerator

by

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ABSTRACT

This report describes the design of a bench-scale fluidized bed incinerator that will capture trace metals on the bed material when firing a hazardous waste. The design is based upon limited tests conducted in an existing laboratory facility. The operating conditions, operating procedures and equipment design are established for greater than 90 percent trace metal capture on the bed material. A surrogate hazardous waste, paint containing lead chromate, was used in the testing. Other trace metals of interest were identified that could be captured by agglomeration on a silica bed material. The design provides the capability of operating in either a single or double stage configuration so that various bed materials or operating conditions could be used to capture different trace metals or to provide more effective capture, if required. The bench-scale fluidized bed incinerator will have the flexibility to operate with several fuels, bed materials, fluxing agents and over a wide range of operating conditions.

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SECTION 1

INTRODUCTION

Emissions of trace metals from the combustion of hazardous waste material is of primary concern to EPA's Office of Solid Waste. Organic material in such waste can be disposed of by incineration; however many trace metals are emitted into the atmosphere from most conventional incinerators. This study was undertaken to evaluate the potential for fluidized bed incinerators to capture the trace metals.

The major activity of this work assignment was to provide a design package for a versatile bench scale fluidized bed incinerator. This design was to be based upon general experience in fluidized bed combustion with particular attention to the operating conditions expected for trace metal capture. The bench scale testing was preliminary in nature to establish the feasibility of the system. A detailed performance analysis of the fluidized bed incinerator was not necessary to design the bench scale unit. Starting with a feasible system, EPA plans to conduct subsequent work using the versatilely designed bench scale facility to thoroughly test the trace metal capture performance on waste materials of specific interest.

OBJECTIVE

The project objective was to design a bench-scale fluidized bed combustor (FBC) to capture trace metals in the bed material during hazardous waste incineration. The use of special designs such as cascading FBC's or a spouted bed and selected bed materials was evaluated for capturing the trace metals in the FBC. Preliminary tests were run in an existing laboratory facility, firing a surrogate hazardous waste to establish the system feasibility and performance. Samples were taken to determine the collection efficiency and to provide design data for the bench-scale FBC.

APPROACH

Four specific tasks were identified for conducting the required project work. These tasks are: waste characterization, testing, FBC design and reporting. The three technical tasks are each discussed in detail in the following sections. The reporting task is represented by monthly technical progress reports and this final report.

Battelle's background in fluidized bed combustion, waste management, and environmental control technology provided a starting point in planning this project. The waste characterization task evaluated different types of waste materials, such as paint, paint sludge or used lubricating oil, that could be used as the surrogate for the testing. All of these wastes contain trace metals of interest to EPA. Candidate bed materials, such as silica, limestone, alumina or glass beads, were evaluated for chemical absorption and physical adsorption of the trace metals onto the bed material. The operating conditions of the FBC were selected to match the trace metal(s) of interest and the particular bed material. It was generally preferred to capture the trace metal as an oxide but consideration was given to cascading beds so that other chemical species of the trace metal could be captured.

A limited amount of experimental testing was done to verify the behavior of the candidate materials in the FBC. After evaluating the available existing facilities at Battelle, the 6-inch Spouted Bed Facility, after modification to operate as a conventional FBC, was chosen as most suitable for this work. These modifications included installing a perforated plate distributor, reactivating the liquid feed system, reactivating the flue gas cyclone and installing a particulate filter. Sample points were provided for the bed material, cyclone capture and filter capture so that a material balance and capture efficiency could be calculated.

The bench-scale FBC is designed for use by EPA to test a variety of hazardous waste streams. A detailed design of the FBC and its integral components such as the distributor, instrumentation and materials of construction are provided. Specifications of auxiliary components such as air supply, startup burner, control and analytical instrumentation are also provided so that existing off-the-shelf equipment can be purchased by EPA. The design is of a quality such that a mechanical contractor can provide a fixed price bid for building the facility.

An operating procedure is provided for the FBC plus typical auxiliaries. This procedure should be revised by EPA after the unit is constructed to include any changes which may have been made to the FBC or any auxiliary equipment which is different from that described. Also EPA's safety procedures should be incorporated into the operating procedure for the specific waste material to be incinerated.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

A fluidized bed combustor can capture on the bed material over 90 percent of the trace metals from the incineration of a surrogate hazardous waste. To maximize this trace metal capture, operating conditions are set at less than 750 C (1350 F), 1.2 meters per second (4 feet per second) superficial velocity and bed material containing up to 0.5 percent sodium carbonate ($Na_2 CO_3$) as a fluxing agent. These conditions are based upon limited testing in order to establish a design basis for this project. More extensive testing is needed to optimize the system and to extend the operation to a wide range of wastes.

A bench scale fluidized bed combustor has been designed to operate in either a single or double stage mode so that additional testing can be conducted by E.P.A. It is recommended that this facility be built by E.P.A. to test a variety of hazardous wastes. The facility can be used to determine the trace metal capture efficiency and operating conditions for a variety of wastes. It will also be possible to evaluate the capabilities of a two stage operation. Some wastes may require higher operating temperatures than those tested in this work in order to achieve complete combustion; testing under a variety of conditions should be done to fully capitalize on this work.

SECTION 3

WASTE CHARACTERIZATION

The combustion of hazardous waste materials containing trace/heavy metals is of concern because of the potential health hazards presented by the trace metals. Consistent with the project objective of trying to capture these metals on the bed material in a fluidized bed combustor, a review was conducted to characterize the hazardous wastes and trace metals of concern. Based upon toxicity and OSHA threshold limit values (TLV), the following six metals were selected as priority concerns: mercury, lead, cadmium, chromium, nickel and cobalt. Other metals which were considered are: antimony, arsenic, barium, beryllium, selenium, silver, and tellurium. It is thought that all of these metals, except mercury, can be captured as a stable oxide under conventional operating conditions for a fluidized bed combustor. The relatively high vapor pressure of elemental mercury presents a special problem that must be addressed separately.

The mechanism for capture of these trace metals, with the exception of mercury, is to agglomerate the metal oxide with silica in the fluidized bed. This capture mechanism will draw from glass chemistry and compounding techniques as well as other applications of agglomeration phenomenon. The addition of a small quantity of sodium carbonate ($Na_2 CO_3$) to the fluidized bed of silica will result in a "tacky" surface. This approach utilizes the chemistry of glass formulations but on the surface of the bed material. The sodium carbonate reacts with the silica[1] to form sodium silicate glasses (water glass) of varying composition and softening temperatures[2] varying downward from that of silica to about 565 C (1050 F). (Temperature higher than the minimum softening temperature may be required to initiate the

reaction between the sodium carbonate and the silica). Initially, a film with a low softening temperature would form on the surface of a silica particle, but this film would continue to react with the silica, causing the softening temperature to rise and the reaction to slow. At temperature near the softening temperature, the particles, within the fluidized bed, will have a tacky surface and thus can stick to other particles.

Nearly all of the trace metals in the form of their oxides will react with the sodium silicate to from glasses of lower water solubility than that of the sodium silicate glass.

This is the proposed basis for capture of trace metals in the fluidized bed combustor. First, particles of the trace metal oxides are trapped by the sticky surface of the bed particles, and the trace metal oxides are incorporated into the glass composition. In favorable circumstances, the trace metals will be trapped as insoluble glasses, greatly easing the problem of disposing of the material.

From prior experience with particle agglomeration,[3] it is known that fine particles tend to attach to the relatively large bed particles in a fluidized bed combustor operating at an agglomerating temperature. The small particles provide a coating to the large particles with a tacky surface. If the temperature is too high or the surface too tacky, a point will be reached where the bed particles will stick to each other and defluidize the bed. An empirical correlation between bed temperature and superficial fluidizing velocity establishes a range of stable fluidization. Figure 3-1 illustrates a typical relationship for stable fluidization for sticky materials as a function of bed temperature and superficial gas velocity.

Industrial waste streams which contain trace metals that might use this control technique are: paint manufacturing, paint spray operations, electroplating, electromelting, photographical chemical, smelting and other basic metal operations.

Paint containing lead-chromate pigment, was chosen as the surrogate hazardous waste to be used in testing this capture mechanism in the laboratory. Paint is a common material which typically contains one or more metallic pigments. The paint was mixed with mineral spirits, a solvent that is the fuel to be incinerated.

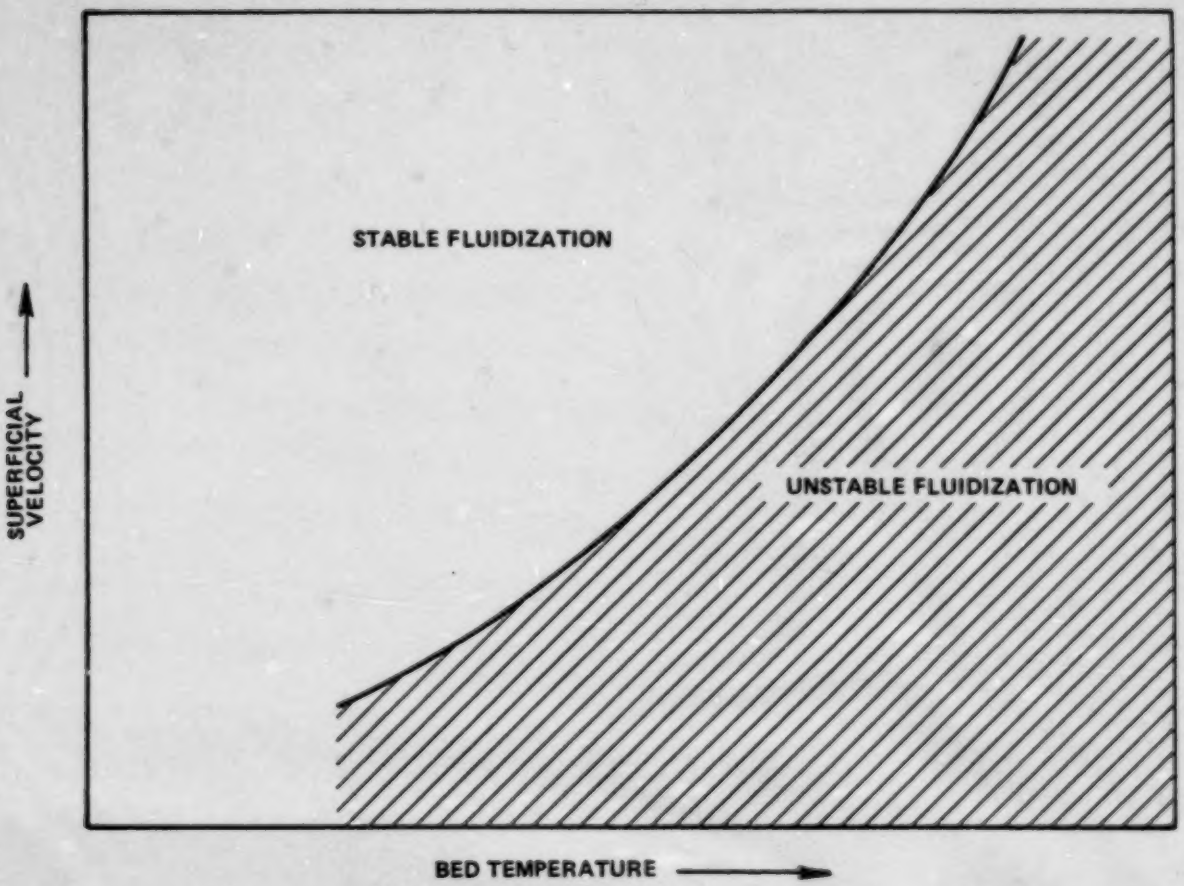


FIGURE 3-1 STABLE FLUIDIZATION CORRELATION

SECTION 4

TESTING

EXPERIMENTAL FACILITY

A detailed sketch of the fluidized-bed combustion unit and auxiliary equipment which was used during the testing phase of the project is shown in Figure 4-1. The combustor has inside dimensions of 0.15 meter (6 inches) diameter and 2.13 meters (84 inches) overall height. The combustion unit is lined with 0.05 meter (2 inches) of castable refractory. The inner lining is a high-density, hard, abrasion resistant refractory, while the outer lining is an insulating refractory. The gas distribution plate is 6.35 mm (1/4-inch) thick and has sixteen 4 mm (5/32-inch)-diameter orifices. The unit is flanged near the top and bottom with a number of nozzles in both the sidewalls and the top for bed introduction, feed introduction, and all of the necessary thermocouples and pressure indicators.

The fluidized-bed combustor is fitted with a natural gas burner in the bed area for heating of the bed material prior to introduction of the waste feed. The fluidizing air, after passing through the distributor plate and bed material, is then exhausted from the unit via a water-cooled stainless steel, 6-inch-diameter line which discharges the dust laden gases into a cyclone dust collector. After the cyclone, the gases pass through a high-purity glass fiber filter and then into the building exhaust system.

Thermocouples and pressure taps are placed at strategic points in the system to monitor temperature of the bed material, freeboard space, and exhaust gas stream. Pressure differentials are measured across the total system, the bed zone, and the dust collection system. The temperature of the bed was controlled during operation by varying the rate of introduction of the waste material into the unit.

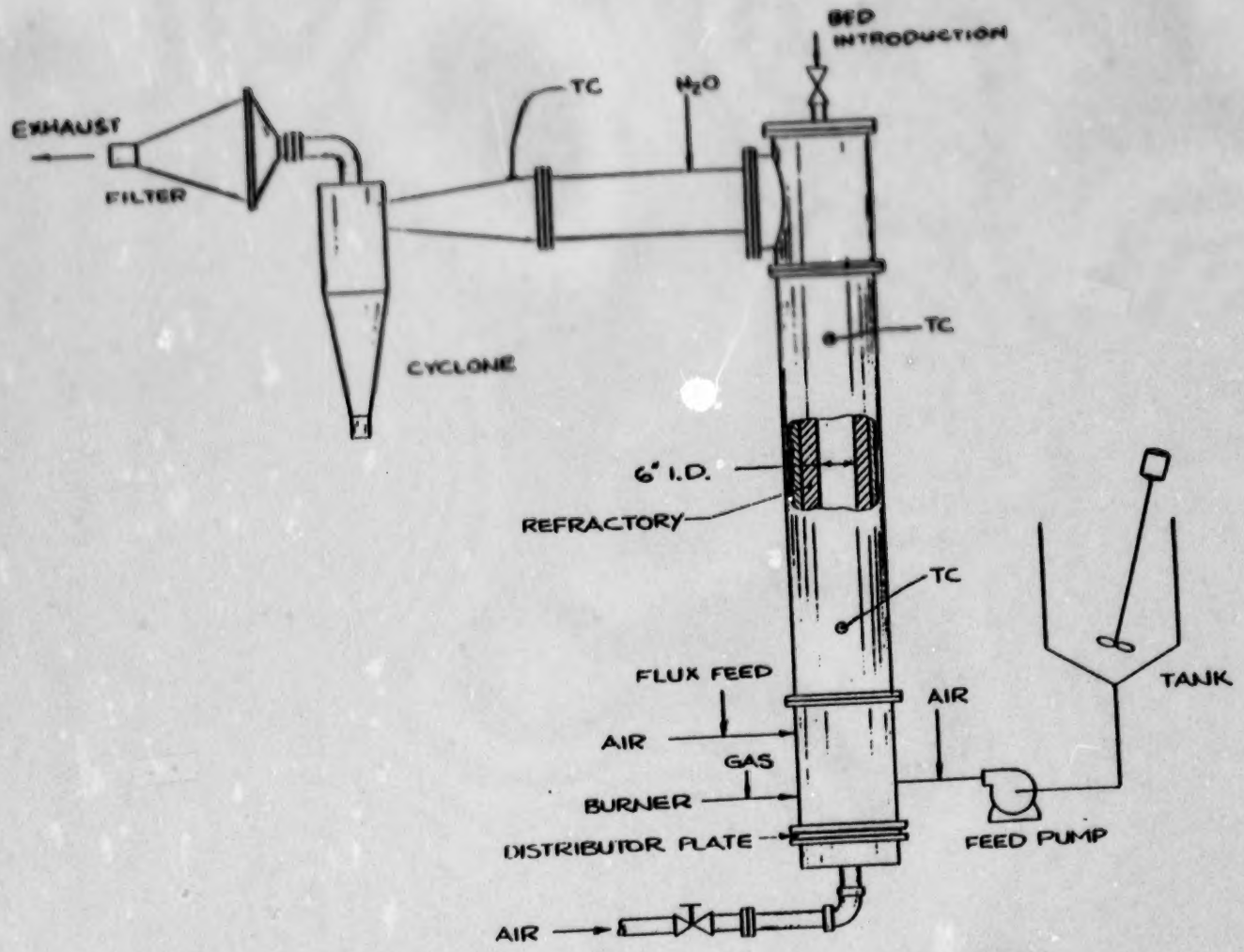


FIGURE 4-1 6 INCH FLUIDIZED BED COMBUSTOR

The surrogate waste material was pumped to a pneumatic feed tube mounted in the side of the combustor 0.1 meter (4 inches) above the distributor plate using a peristaltic pump. This same system was used to feed mineral spirits in the preliminary runs. The feed tube is a single barrel 6.35 mm (1/4-inch)-diameter, water-cooled type that allowed dispersion of the feed by varying the amount of air to the feed tube.

TEST PROCEDURE

The general test procedure that was followed during testing consisted of:

(1) Fluidizing air flow, sufficient to prevent bed material from flowing down through the orifice plate, was started.

(2) A 9 kg (20-pound) starter bed of minus 20 plus 100 mesh silica sand was introduced through the opening in the top of the combustor.

(3) The fluidizing air was increased sufficiently to fluidize the sand.

(4) The natural gas start-up burner was ignited and gas was metered to the burner to provide the heat required to raise the temperature of the bed material to a level suitable for ignition of the surrogate waste feed. (650 C/1200F)

(5) The flow of surrogate waste material into the combustor was adjusted to maintain proper/pre-determined combustion conditions.

(6) A clean cyclone dust collection container and filter paper were installed.

(7) The unit was operated at pre-selected conditions for a selected period of the time (usually 2 hours).

(8) Throughout the test the fluxing agent (Na_2CO_3) was added to the bed intermittently via a pneumatic injector located in the sidewall of the combustor.

(9) The exhaust gases were analyzed for oxygen, carbon dioxide and carbon monoxide content.

After operation for the selected time period, samples of the bed material, surrogate feed mixture, cyclone dust, and filter dust were taken for analyses. Lead and chromium analyses were performed on the various samples.

TEST RESULTS

Seven tests were made in the 6-inch FBC while feeding surrogate hazardous waste. Six of these tests used paint as the source of trace metals and one test was with used motor oil. A preliminary test was made, without trace metals in the fuel, to check out the equipment and to establish baseline operating conditions prior to testing the surrogate hazardous wastes. The operating conditions for each of the tests are presented in Table 4.1. The primary variables were temperature, velocity and the use of sodium carbonate ($Na_2 CO_3$) as a fluxing agent. The combustion temperatures ranged from 700 to 850 C (1300 to 1600 F) and the superficial velocity varied from 1.0 to 1.2 meters per second (3.3 to 4.0 feet per second). During the preliminary test a shallow, 0.15 meter (6 inch), static bed depth was tried and considerable difficulty was encountered in burning mineral spirits. Therefore a 0.3 meter (12 inch) deep bed was used to get more complete combustion in all the tests with surrogate hazardous waste as the fuel. This amounted to 9 kilograms (20 pounds) of minus 20 plus 100 mesh sand.

Greater than 90 percent of the trace metals can be captured on the bed material in a fluidized bed incinerator. These tests establish the operating conditions and verify the capture mechanism. A significant amount of the trace metals were captured with the bed material in one of the tests without the fluxing agent. Thus the requirement for the fluxing agent is less critical depending upon the waste material and the operating conditions. The addition of a fluxing agent to the system is more certain and controllable. Further testing is needed in order to maximize the capture of trace metals and to extend the operation to more materials.

Table 4.2 presents the trace metal analyses for samples taken during these tests. The calculated trace metal capture for each sample is presented in Table 4.3. These calculations are based upon the total output of trace metals since a satisfactory trace metal material balance was not achieved for the tests. This problem is thought to be a result of the sampling and analysis of the surrogate hazardous waste feed stream.

The paint containing lead chromate ($PbCrO_4$) was diluted with mineral spirits to provide a surrogate hazardous waste containing approximately 1 percent lead and 0.3 percent chromium. This 1:50 mixture of paint and solvent caused the suspended solids in the paint, i.e., the lead chromate

TABLE 4.1 TEST OPERATING CONDITIONS

Test Number	Fuel	Combustion Temperature, C/(F)	Fluidizing Velocity, m/s/(ft/sec)	Fluxing Agent, Percent of Bed	Waste Feed Time, min	Waste Feed Rate ml/min	Waste Feed Total ml	Remarks
1	Paint	871/(1600)	1.22/(4.0)	0	90	32.0	2880	
2	Paint	760/(1400)	1.28/(4.2)	0	100	25.4	2540	
3	Paint	760/(1400)	1.00/(3.3)	0.5	120	26.4	3170	Bed became sticky
4	Paint	704/(1300)	1.15/(3.8)	0.2	92	29.3	2700	
5	Paint	704/(1300)	1.22/(4.0)	0.5	130	22.1	2890	
6(a)	Paint	732/(1350)	1.22/(4.0)	0.5(b)	95	36.0	3420	Bed became sticky
7(c)	Oil	704/(1300)	1.22/(4.0)	0	15(d)	25	375	

(a) Bed used was that from Test 5.
(b) In addition to that added in Test 5.
(c) Feed was used motor oil.
(d) Test discontinued after 15 minutes due to incomplete combustion of waste.

TABLE 4.2 TRACE METAL ANALYSES[a]

Test Number	Fuel	Feed			Bed Material			Cyclone Capture			Filter Capture		
		Quantity, Kg	Pb, %	Cr, %	Quantity, Kg	Pb, %	Cr, %	Quantity, Kg	Pb, %	Cr, %	Quantity, Kg	Pb, %	Cr, %
1	Paint	2.500	0.488 0.259[b]	0.029 0.017[b]	9.072	0.0002	0.0005	0.0069	0.012	0.049	0.00216	1.2	0.45
2	Paint	2.205	0.068 0.101[b] 0.124[b]	0.004 0.007[b] 0.008[b]	8.618	0.06	0.0035	0.0041	5.14	0.58	0.00158	8.1	0.75
3	Paint	2.752	0.066 0.086[b]	0.004 0.006[b]	8.800	0.07	0.004	0.0081	1.10	0.13	0.00144	7.5	0.22
4	Paint	2.344	0.154 0.199[b] 0.224[b]	0.010 0.012[b] 0.013[b]	9.072	0.09	0.005	0.0005	2.05	0.61	0.00183	11.3	00.46
5	Paint	2.491	0.153 0.158[b]	0.010 0.010[b]	9.072	0.11	0.008	0.0019	4.40	0.16	0.00139	34.1	2.51
6	Paint	2.969	0.163	0.009	9.072	0.17	0.02	0.0019	4.9 4.2[b]	0.24 0.21[b]	0.00322	36.1 30.9[b]	1.08 1.10[b]
7	Oil	0.338	0.03	0.004	9.072	0.02	0.01	0.0015	3.9	0.44	0.00018	4.33 4.67[b]	0.09 0.11[b]
Solvent			0.0001	0.0001									
Fresh Bed Material						0.0004	0.0004						

(a) These data represent the experimental results of the samples collected during each test. The total stream quantity is reported and the quantity of lead (Pb) and chromium (Cr) in each test sample.

(b) Duplicate analysis of bed material.

TABLE 4.3 TRACE METAL CAPTURE[a]

Test Number	Bed Material			Cyclone Capture		Filter Capture	
	Fuel	Mass, g	%[b]	Mass, g	%[b]	Mass, g	%[b]
1	Paint	0.02/0.04	0.3/9.5	0/0	0/0	0.03/0.01	0.5/2.4
2	Paint	5.17/0.30	93.8/90.9	0.21/0.02	3.8/6.1	0.13/0.01	2.3/3.0
3	Paint	6.16/0.35	95.5/94.6	0.09/0.01	1.4/2.7	0.11/0.01	1.7/2.7
4	Paint	8.16/0.45	97.0/97.8	0.01/0.0	0.1/0	0.21/0.01	2.5/2/2
5	Paint	9.98/0.73	94.8/94.8	0.08/0.0	0.8/0	0.40/0.04	3.8/4.2
6	Paint	15.4/1.81	93.5/97.8	0.08/0.0	0.5/0	0.99/0.04	6.0/2.2
7	Oil	1.81/0.91	96.3/98.9	0.06/0.01	3.2/1.1	0.01/0.0	0.5/0.0

(a) Data presented are for: Lead/Chromium (Pb/Cr).

(b) The data are presented as the percentage of each trace metal captured based upon the total mass measured in the system.

pigment, to drop out of suspension. The feed system included a mixer in the feed container and a recycle line from the pump discharge to keep the solids mixed during the test. During the tests it was observed that the solids would settle if not stirred vigorously and continuously. The sample of feed material was taken from the pump circulation line and it is thought that these samples are not providing reliable concentrations of trace metals. Higher circulation rates may have kept the solids in suspension. An initial review of the sample analyses indicated that the concentrations of lead and chromium were low compared to the mixture blend so a duplicate analysis of the feed samples was made (reported in Table 4.2). This indicated that the problem of keeping the solids suspended carried over into the sample analysis also. Further confirmation that the trace metal concentration in the fuel samples is not correct comes from the fact that in all tests, except Test Number 1, there is significantly more lead and chromium in the bed than is reported from the feed. For these reasons, the feed analyses have not been used in determining the percentage trace metal capture. This approach is appropriate for this study because the trace metal concentration of each of the output streams is the significant data required for evaluation. The concentration of trace metals in the feed stream would allow the mass balance to be determined but would not alter the conclusion that over 90 percent of the trace metals were captured in the bed material. For future work, a diluent other than mineral spirits would be used to maintain a stable suspension of solids (trace metals) in the feed stream.

Test Number 1 was operated at high temperature without fluxing agent. The trace metal capture in this test was quite poor but the results are questionable as this was the only test where the quantity of trace metals in the outlet streams was less than the reported quantity of trace metals into the system. The test was inconsistent with Test Number 2 which operated at lower temperature also without fluxing agent. The 90 percent trace metal capture on the bed material provides a high standard for comparison of the other tests. It is thought that lead served as the fluxing agent in this test. This result is consistent with earlier work.[5]

Test Number 3 was a critical experiment to establish the limits of operating the FBC with sticky bed material. Test Number 6 also resulted in a sticky bed which established that the operating conditions had to be less than 732 C (1350 F) and less than 0.5 percent fluxing agent ($Na_2 CO_3$). In

both of these tests, the bed contained several agglomerates of sand particles which had stuck together. In Test Number 4 this is attributed to the high temperature and in Test Number 6 it is attributed to an excessive quantity of fluxing agent.

Tests Number 4 and 5 represent the desired operating conditions for trace metal capture.

Test Number 7 was the only test with used motor oil as the fuel. The combustion temperature was held at 700 C (1300 F) for trace metal capture but this resulted in incomplete combustion for this fuel so that this test was terminated early and the results are of less value. Some fuel preheat, higher combustion temperature and/or longer residence times are expected to solve this problem but additional tests were not performed due to time and funding limitations. Additional tests are recommended to establish the operating conditions for a wider range of fuels including used motor oil. Optimization of the quantity of fluxing agent used and operating temperature for other types of trace metals and fuels remains to be determined.

SECTION 5

DESIGN

The design of the bench scale fluidized bed incinerator is based upon general experience in this technical arena and upon the limited testing conducted on this program to establish feasibility of the system. While a very simple system was used to establish feasibility, future work to be conducted by EPA may address staged operation with distinct trace metal capture in each stage. The unit design provides the flexibility to operate with different bed materials, fluxing agents, or operating conditions in each stage.

DESIGN BASIS

The bench-scale fluidized bed combustor (FBC) was designed to burn hazardous wastes containing trace metals. The system is capable of burning either solid or liquid waste materials. A fluxing agent can be added to the fluidized bed in order to improve capture of the trace metals on the bed material. The FBC temperature can be controlled by modulating the fuel feed and fluidizing air rates. The 6-inch diameter combustor is designed for a heat release rate of approximately 34 mega Joule per hour (32,000 Btu/hr). This corresponds to a superficial velocity of 0.9 meters per second (3 feet per second) at 760 C (1400 F). The design is based on a 0.3 meter (12 inch) deep bed of silica sand, 20 x 100 mesh, for this fluidization condition.

Considerable flexibility is designed into the system so that a wide range of operating conditions are possible. A single stage operation is possible by using one FBC. Two FBC's can be operated in series to provide two separate operating stages. This feature provides the ability to operate

with two different bed materials, or fluxing agents, to capture distinct trace metals in each bed. The FBC design is the same for both stages. Figure 5-1 shows a schematic diagram of the system with two stages in series. The detailed drawings of the system are included in the Appendix.

The upper section of the combustor is expanded to facilitate solids disengagement from the flue gas. After exiting the combustor, the flue gases are quenched to 150 C (300 F) by spray injection of cooling water. The gases then pass through a cyclone and filter before being exhausted from the system.

When operating two FBC's in series, the gas condition into the second FBC will affect the distributor plate and bed behavior. For this reason, a cyclone was specified in the duct between the two units in order to minimize any plugging caused by dust from the first stage FBC. The temperature of the gas into the second stage FBC may need to be controlled separately from the bed temperature but this will depend upon the specific conditions being tested.

PROCESS FLOW DIAGRAM

The process flow diagram for the bench scale FBC is included in the Appendix. The design basis heat and material balance is included on this diagram. In general these conditions represent normal operating conditions rather than design maximum conditions. Table 5-1 provides additional information on the design specifications for the system. Detailed specifications for the major components are provided in the respective sections.

PIPING AND INSTRUMENTATION DIAGRAM

This drawing (included in the Appendix) provides the schematic arrangement for the system instrumentation. A line list is included on the drawing which establishes the pipe sizes and valves which are needed to install the system.

The instrumentation diagram (included in the Appendix) provides the control panel layout and a list of the instruments. Table 5-2 provides the instrument duty specifications for each component so that they can be purchased from standard equipment suppliers.

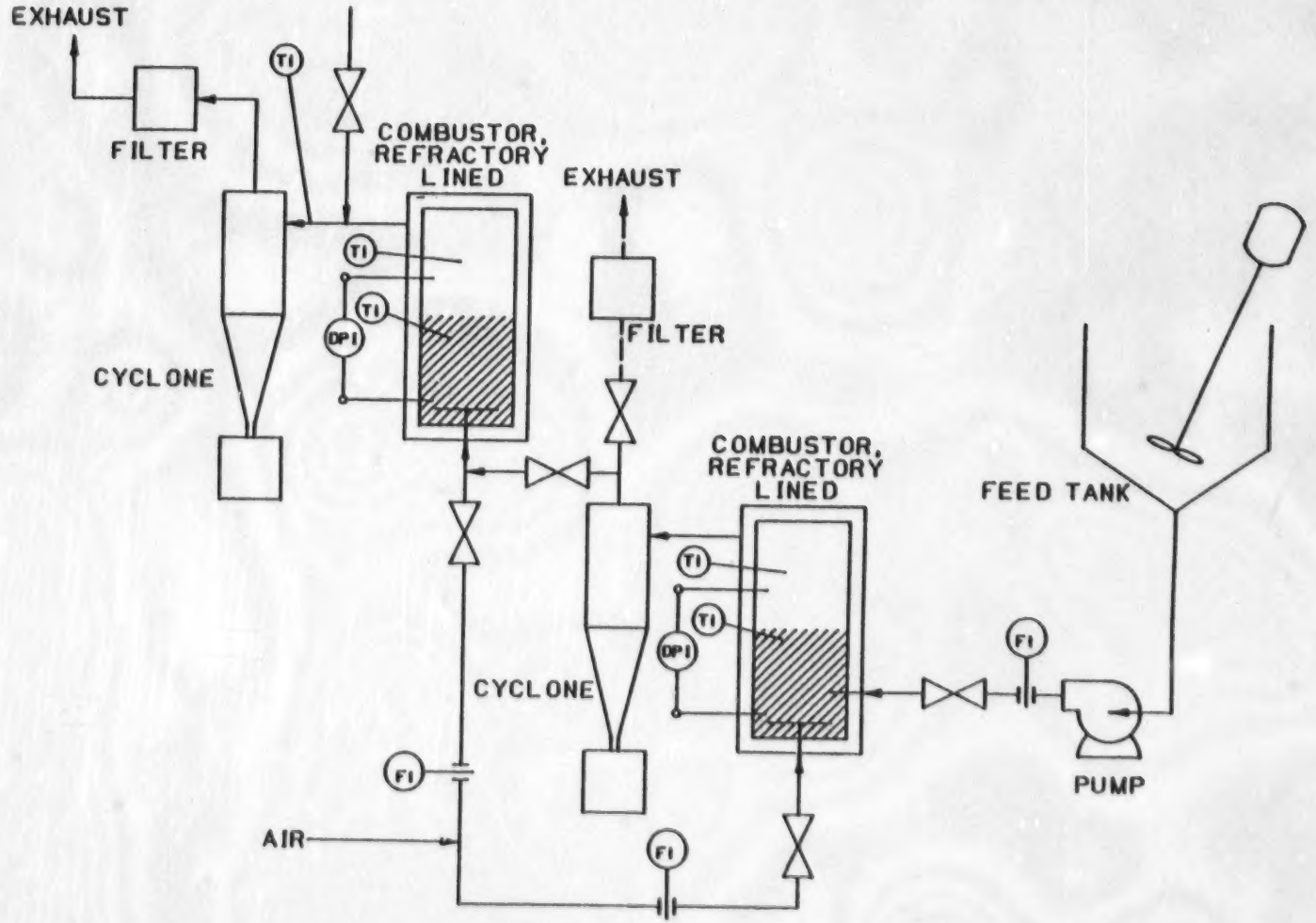

6 INCH FLUIDIZED BED COMBUSTION FACILITY
EXHAUST
FILTER
TI
COMBUSTOR, REFRACTORY LINED
EXHAUST
TI
TI
DPI
FILTER
CYCLONE
COMBUSTOR, REFRACTORY LINED
FEED TANK
TI
TI
DPI
FI
CYCLONE
FI
PUMP
AIR
FI

FIGURE 5-1

TABLE 5-1. SPECIFICATION - FLUIDIZED BED COMBUSTION FACILITY

	Operating	Design
Combustor		
Temperature, C/(F)	815/(1500)	1093/(2000)
Pressure, kPa/(psig)	13.8/(2)	34.5/(5)
Air flow, kg/s/(lb/hr)	1.26E-2/(100)	2.52E-2/(200)
Flue Gas Flow, kg/s/(lb/hr)	1.38E-2/(110)	2.77E-2/(220)
Feed Rate, kg/s/(lb/hr)	1.26E-3/(10)	2.52E-3/(20)
Heat Release, kJ/s/(Btu/hr)	35.3/(120,000)	70.6/(240,000)
Superficial Velocity, m/s/(ft/sec)	1.5/(5)	3.0/(10)
Bed Material, microns	850 x 150 20 x 100 mesh sand	850 x 420 20 x 40 mesh sand
Cyclone		
Temperature, C/(F)	150/(300)	815(1500)
Pressure, kPa/(psig)	13.8/(2)	34.5/(5)
Differential Pressure, kPa/(in. W.C.)	1.74/(7)	6.97(28)
Inlet Velocity, m/s/(ft/sec)	10.7/(35)	21.3/(70)
Dust Loading, g/m^3/ (grain/ft^3)	2.75/(1.2)	11.44/(5)
Inlet Particle Size, microns	150 (100 mesh)	250 (60 mesh)
Dust Filter		
Flue Gas Flow, kg/s/(lb/hr)	1.38E-2/(110)	2.77E-2/(220)
Temperature, C/(F)	150/(300)	204/(400)
Pressure, kPa/(psig)	13.8/(2)	34.5/(5)
Differential Pressure, kPa/(in.W.C.)	1.24/(5)	2.49/(10)
Filter medium	Glass fiber	Glass fiber
Particle Size,	1	1
Startup Burner		
Heat Release, kJ/s/Btu/hr)	35.3/(120,000)	
Fuel	Natural gas	
Outlet Temperature, C/(F)	815/(1500)	
Ignition and flame safety controls required		
Air Supply		
Air Flow Rate, kg/s/(lb/hr)	1.26E-2/(100)	2.52E-2/(200)
Temperature	Ambient	Ambient
Discharge Pressure, kPa/(psig)	13.8/(2)	34.5/(5)
Fuel Supply		
Fuel Flow Rate, kg/s/(lb/hr)	1.26E-3/(10)	2.52E-3/(20)
Temperature	Ambient	Ambient
Discharge Pressure, kPa/(psig)	34.5/(5)	34.5/(5)
Flue Gas Quench		
Heat Duty, kJ/s/(Btu/hr)	35.3/(120,000)	70.6/(240,000)
Water rate, kg/s/(lb/hr)	1.89E-2/(150)	3.78E-2/(300)
m/s/(gpm)	1.89E-5/(0.3)	3.78E-5/(0.6)
Pressure	5	10

TABLE 5-2. INSTRUMENTATION LIST

Tage Number	Service	Duty/Specification
Temperature		
TI/TR	Temperature Indicator & Recorder	12 point digital
TI-1A & 1B	Fluidized Bed (2" level)	Type K, 650/1100 C, (1200/2000 F)
TI-2A & 2B	Fluidized Bed (22" level)	Type K, 650/1100 C, (1200/2000 F)
TI-3A & 3B	Combustor Freeboard	Type K, 650/1100 C, (1200/2000 F)
TI-4A & 4B	Exhaust Gas	Type K, 100/300 C, (200/600 F)
TI-5A & 5B	Service Air	Type K, 21 C/(70F)
Pressure		
PI-1A & 1B	Lower Bed Level	0/10 kPa/(0/30 in. W.C.)
PI-2A & 2B	Combustor Freeboard	0/10 kPa/(0/30 in. W.C.)
PI-10	Liquid Waste Feed Line	0/40 kPa/(0/150 in. W.C.)
PI-30 & 31	Fluidizing Air Line	0/40 kPa/(0/150 in. W.C.)
PI-32	Feed Air Line	0/40 kPa/(0/150 in. W.C.)
PI-33	Flux Feed Air Line (F-101A)	0/40 kPa/(0/150 in. W.C.)
PI-34	Start Up Burner Air (H-101A)	0/10 kPa/(0/30 in. W.C.)
PI-35	Flux Feed Air Line (F-101B)	0/40 kPa/(0/150 in. W.C.)
PI-36	Start Up Burner Air (H-101B)	0/10 kPa/(0/30 in. W.C.)
Differential Pressure		
DPI-1A & 1B	Bed Differential	0/15 kPa(0/50 in. W.C.) w/reverse air purge
DPI-40A & 40B	Cyclone Differential	0/15 kPa(0/50 in. W.C.) (magnahelic)
DPI-41A & 41B	Filter Differential	0/15 kPa(0/50 in. W.C.)(magnahelic)
Flow		
FI-10	Liquid Fuel Flow	100 ml/min @ 65 C/(150 F) 1.03MPa (150 psi)
FI-20A & 20B	Flux Feed Flow	500 g/hr @ ambient conditions
FI-21	Solid Fuel Flow	2.7 g/s @ ambient conditions
FI-30 & 31	Fluidizing Air Flow	0.57 m^3/min (20 scfm)
FI-32	Liquid Feed Air Flow	
FI-33	Flux Feed Air Flow (F-101A)	
FI-34	Burner Air Flow (F-101A)	
FI-35	Flux Feed Air Flow (F-101B)	
FI-36	Burner Air Flow (H-101B)	
FI-50	Exhaust Gas Cooling H_2O (I-101A)	3.15 E-6 m^3/s, (3 gph) @ ambient conditions
FI-51	Exhaust Gas Cooling H_2O (I-101B)	3.15 E-6 m^3/s, (3 gph) @ ambient conditions
FI-60	Burner Natural Gas (H-101A)	4.72 E-4 m^3/s, (1 scfm)
FI-61	Burner Natural Gas (H-101B)	4.72 E-4 m^3/s, (1 scfm)

EQUIPMENT LIST

Each major piece of equipment is specified either by detailed design or by a suggested specific model of commercially available equipment in Table 5-3. Several manufacturers may be able to provide equivalent components to the suggested model with minimal problem to the overall system. These specifications provide the basis for obtaining price quotations or for procuring the equipment.

GENERAL ARRANGEMENT

This drawing (included in the Appendix) provides the overall dimensions and arrangement of the facility. This drawing can be used for installing the facility. The equipment support must be integrated into the laboratory facility where the FBC is being installed.

COMBUSTOR

The detailed drawing of the combustor provides the information necessary for manufacture of this component by a machine shop or mechanical contractor. The refractory specification is based upon recommended materials although various manufacturers may have equivalent materials. Manufacturers recommendations must be followed for preparing, installing and curing the refractory.

The distributor plate is designed to be a general purpose component that can be easily replaced, or modified, if specific test conditions require another design. Some distortion of the distributor plate is expected as a result of thermal expansion during the heat up and operation of the FBC. This is not normally a problem as long as the distributor plate requires a measurable pressure drop and provides uniform air distribution to the FBC. Since the plate is not designed to prevent back-sifting, some air flow should be maintained on the unit whenever bed material is in the FBC. Provisions have been made to withdraw the bed material when the unit is shut down.

Separate feed nozzles have been provided for the liquid feed system and for the solid feed system. It is not expected that both would be used at

TABLE 5-3. EQUIPMENT LIST

Equipment Number	Equipment Description	Specification and/or Manufacturer
I-101A & 101B	6" ϕ Fluidized Bed Units	See Drawing No. G-7424-04
C-101A & 101B	Cyclone Dust Collectors	Fisher-Klosterman XQ Series (Size 3)
A-101A & 101B	Filter & Housing	See Drawing No. G-7424-05, 0.2m x 0.3m (8" X 12") Glass Fiber Filter Paper
P-101	Liquid Waste Feed Pump	Peristaltic (w/Buna N Tubing)
F-101A & 101B	Fluxing Agent Feeder	Volumetric Screw Feeder (Acrison Model 105A)
H-101A & 101B	Start Up Heater	Maxon #11681 Pilot Burner (w/UV Sensor & Flame Safety Control)
F-102	Solid Waste Feeder	Volumetric Screw Feeder (Acrison Model 105D)
T-101	Liquid Waste Mix Tank	Stainless Steel Tank with Conical Bottom, 0.02 m^3 (5 gal), 0.3m ϕ X 0.3m (1 ft ϕ X 1 ft)
S-101	Liquid Waste Agitator	Eastern, Heavy Duty, Variable Speed (VWR #58964-007)
P-101	Liquid Waste Feed Pump	Peristaltic

the same time although this is possible. Both feed nozzles are designed for air injection to assure fuel dispersion within the FBC and to help prevent the fuel from sticking or burning prematurely in the feed line.

FLUE GAS SYSTEM

Details are provided for the flue gas duct out of the combustor and for the filter housing (drawing is included in the Appendix). The hot flue gas duct includes the water spray nozzle to quench the gas temperature entering the cyclone. The filter housing is specifically designed to use standard 0.2 m x 0.3 m (8" x 12") glass fiber filters. The filters will need to be replaced after each test to limit the pressure drop and to avoid contamination between tests.

OPERATING INSTRUCTIONS

The following sequential procedures have been prepared for operating the 6-inch FBC facility. These procedures provide an initial basis for skilled technicians to startup, operate and shut down the facility. When the technicians become experienced at operating this facility, they should prepare specific detailed procedures for their operation that replace these initial procedures. As various hazardous wastes are burned in this facility, specific procedures may be required for handling the waste materials, or its ash residue, that are not included in this general procedure. It is recommended that specific test procedures be prepared for each test condition to complement the general operating instructions for the facility.

Pre Start-Up. Prior to putting bed material into the combustor, the following steps should be followed:

1. Start purge air flows to bed pressure taps to prevent backflow of bed.
2. Set fluidizing air (FI-31) at 8.5 m^3/hr (5 scfm).
3. Start water flow through cooling jacket of feed gun.
4. Set burner air at preselected level.
5. Start air flow to feed gun.
6. Start air flow to flux feed nozzle.

7. Install clean cannister on cyclone dust collector.
8. Insure that flue gases are properly exhausted from area.
9. Open main water valve to flue gas quench and activate temperature control.

Start-Up. Add bed material (weighed) to top of combustor.

10. Fluidize bed by increasing air flow to desired velocity.
11. Turn on natural gas to burner and ignite. (FI-60)
12. Regulate natural gas flow to give bed temperature increase of approximately 10 C per minute (20 F per minute).
13. Install clean, weighed filter paper and cyclone cannister just prior to starting waste feed.

Operation

14. When bed temperature reaches ignition temperature of waste (540 to 650 C), start waste fuel flow to combustor.
15. Insure that ignition of waste is occurring by slowly decreasing natural gas flow to burner and observing that the temperature does not fall below approximately 650 C. The temperature should increase.
16. Bring bed temperatures to desired operating level by discontinuing natural gas to burner and increasing waste feed flow.
17. Maintain bed temperature by adjustment of waste feed flow.

18. Throughout test run, monitor all temperatures, pressure and flows.

Shutdown

19. After operation for desired time, simply discontinue waste feed flow.
20. After bed cools below 540 C, the fluidizing air can be reduced
21. Remove filter paper and cyclone cannister.

22. After bed cools sufficiently, the bed material can be removed using a vacuum cleaner through the angled 2-inch nozzles on the combustor.
23. To avoid backsifting and plugging nozzles, do not completely shut off, purge, feed air flow, or fluidizing air at any time while bed materials is in the combustor.
24. After all bed material is removed the air flows can be discontinued.

SECTION 6

QUALITY ASSURANCE

A quality Assurance Plan was prepared for this work assignment in accordance with EPA's "Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans", QAMS-005/80, December 1980. Battelle's Laboratory Record Book Number 39434 was used to record all experimental data and test information. Richard Heffelfinger served as Battelle's Quality Assurance Officer to assist the project staff in conducting this work assignment.

Samples of solids were collected from three different locations in the fluidized bed combustion system. A sample of the bed material was withdrawn at the conclusion of each experiment for analysis of trace metals. The mixing action of the fluidized bed is excellent so that a grab sample is representative of the entire bed. Composite samples of the cyclone capture and baghouse capture were taken for analysis of the trace metals which were not captured in the fluid bed.

Samples were placed in glass or plastic containers to avoid risk of contamination. The samples were recorded in the laboratory record book and were submitted for analysis on a weekly basis.

The continuous gas analyzers received a sample from the flue gas line at the fluidized bed combustor outlet. The sample was drawn through a sample conditioning system including a filter and an ice bath by a vacuum pump. The gas flow rate into each analyzer was measured by a rotameter. Data from the continuous analyzers were recorded on strip chart recorders and were periodically entered into the laboratory record book.

A Battelle conducted Q.A. system audit was conducted on February 2, 1984. The audit addressed record keeping, handling of samples, and calibration of instruments. No problems or deficiencies were found.

Atomic Absorption Spectrophotometry (AAS)

Battelle has four atomic absorption spectrophotometers in service and these were used to support this project.

The Perkin-Elmer Model 5000 spectrophotometer in the AAS laboratory is equipped with an HGA-500 graphite furnace, an AS-40 furnace autosampler, and an AS-50 autosampler for flame operation. Coupled with the appropriate autosampler, either flame or flameless analyses for up to six elements on 35 samples are performed unattended, with all results reported directly in concentration. The AS-40 furnace autosampler permits automatic standard additions and/or matrix modification, with the resulting improvement in accuracy and turnaround time.

The Perkin-Elmer Model 603 AAS, equipped with the HGA-220 graphite furnace, is a highly versatile instrument capable of performing in the flame or flameless operating modes. The AS-1 automatic sampler developed for facilitation of flameless determinations is available at Battelle. Comparable trace metal data may also be acquired using Battelle's Perkin-Elmer Model 305B AAS combined with the HGA-2000 graphite furnace.

A four point calibration curve is maintained for each AAS analysis. A procedure blank and reagent blank are routinely analyzed with every ten samples. A standard flyash sample, NBS SRM 1633, is used to determine accuracy and precision. The detection limit for trace metals by AAS is 1 ppm and accuracy and precision are within 10 percent of the test value.

Flue Gas Analysis

Continuous gas analyzers provided a record of flue gas composition for each test. Nondispersive infrared (NDIR) analyzers were used to measure CO and CO_2 concentrations. A paramagnetic oxygen (O_2) analyzer was also used.

For the flue gas sampling system, each instrument was zeroed and spanned prior to each test run. Standard gas mixtures were used to provide adequate range on each instrument. For daily use, only a zero and a single

point span set was used. This point was checked against multipoint calibration curves for each instrument. Particular attention was directed towards maintaining constant line sample volumes and pressures during the calibrations and sampling. Records of the calibrations were maintained in the laboratory record book.

SECTION 7

SAFETY

A project safety review was held prior to running the laboratory tests. The major safety concern was the exposure of personnel to flue gases containing trace metals. Precautions to minimize this risk were: a rigorous leak check at operating temperature to assure that the total leakage rate did not exceed 800 cm^3/min.; respirators were to be worn when handling dust collected in the cyclone and the filter; ash, used bed material and unused feed material were to be disposed of as chemical wastes.

These precautions pertain to the specific laboratory facility which was used at Battelle. Similar precautions are appropriate for EPA when operating the FBC designed in this project. The facility's small size makes it convenient to use positive pressure through the whole system. This requires rigorous leak checking to minimize leaks of toxic or carcinogenic materials into the work environment. It is feasible to operate the system under a slight negative pressure in order to avoid this problem. The decision of whether to use an induced or forced draft depends upon the specific hazardous waste and how it must be handled. The designed facility is capable of operating in either mode.

REFERENCES

1. "The Properties of Glass", George W. Morey, Reinhold Publishing Corporation, 1938

2. "Glass Engineering Handbook", E. B. Shand, McGraw Hill Book Company, 1958

3. Goldberger, W. M., "Collection of Fly Ash in a Self-Agglomerating Fluidized-Bed Coal Burner" (ASME 67-WA/FU-3) ASME Annual Meeting, November 12-17, 1967, Pittsburg, Pa.

4. Work Assignment, EPA "Bench Scale Evaluation of Trace Metal Retention When firing Hazardous Waste in a Fluidized Bed Incinerator" dated October 4, 1983, Contract No. 68-02-3169, Task 46.

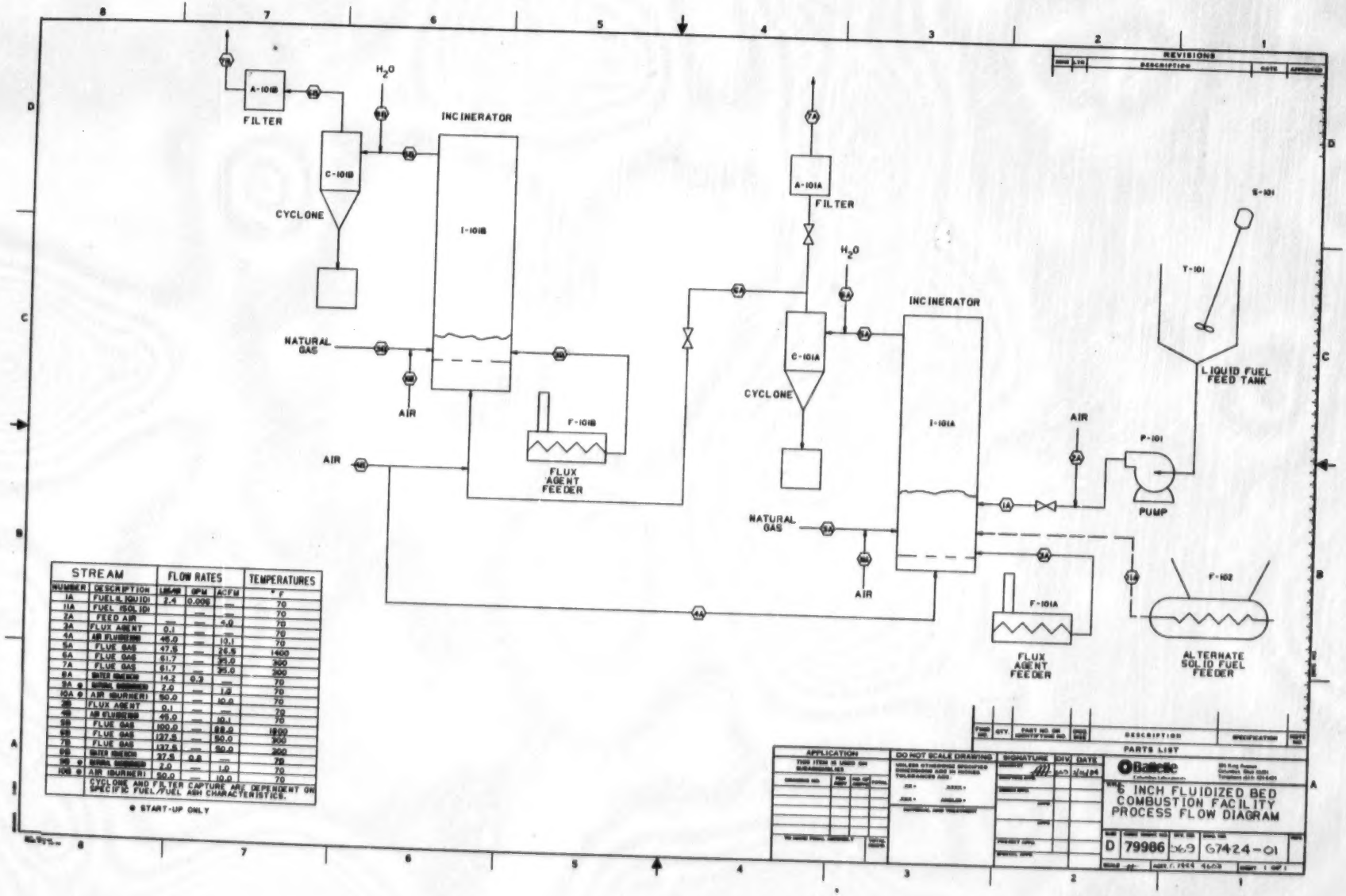
5. "Fluidized Bed Incineration of Selected Carbonaceous Industrial Wastes", EPA Report No. 12120, March, 1972.

APPENDIX

FLUIDIZED BED INCINERATOR DRAWINGS

The following drawings represent the design of the bench scale fluidized bed incinerator. The drawings are described in Section 5 (Design) of the report. The complete drawing package includes:

Drawing Number	Description
G-7424-01	Process Flow Diagram
G-7424-02	Piping and Instrumentation
G-7424-03	Instrument Panel
G-7424-04	Fluidized Bed Combustor
G-7424-05	Exhaust Gas Duct
G-7424-06	Filter Housing
G-7424-07	General Arrangement



STREAM NUMBER	DESCRIPTION	FLOW RATES LB/HR	GPM	ACFM	TEMPERATURES °F
1A	FUEL & LIQUID	2.4	0.008	—	70
1IA	FUEL (SOLID)		—	—	70
2A	FEED AIR	—	—	4.0	70
3A	FLUX AGENT	0.1	—	—	70
4A	AIR (FLUIDIZING	46.0	—	10.1	70
5A	FLUE GAS	47.5	—	24.5	1400
6A	FLUE GAS	61.7	—	35.0	300
7A	FLUE GAS	61.7	—	35.0	300
8A	WATER (MAKE-UP)	14.2	0.3	—	70
9A *	WATER (CHARGE)	2.0	—	1.0	70
10A *	AIR (BURNER)	50.0	—	10.0	70
2B	FLUX AGENT	0.1	—	—	70
4B	AIR (FLUIDIZING	46.0	—	10.1	70
5B	FLUE GAS	100.0	—	22.0	1800
6B	FLUE GAS	137.8	—	30.0	300
7B	FLUE GAS	137.8	—	30.0	300
8B	WATER (MAKE-UP)	37.5	0.8	—	200
9B *	WATER (CHARGE)	2.0	—	1.0	70
10B *	AIR (BURNER)	50.0	—	10.0	70
	CYCLONE AND FILTER CAPTURE ARE DEPENDENT ON SPECIFIC FUEL/FUEL ASH CHARACTERISTICS.				

* START-UP ONLY

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

PARTS LIST

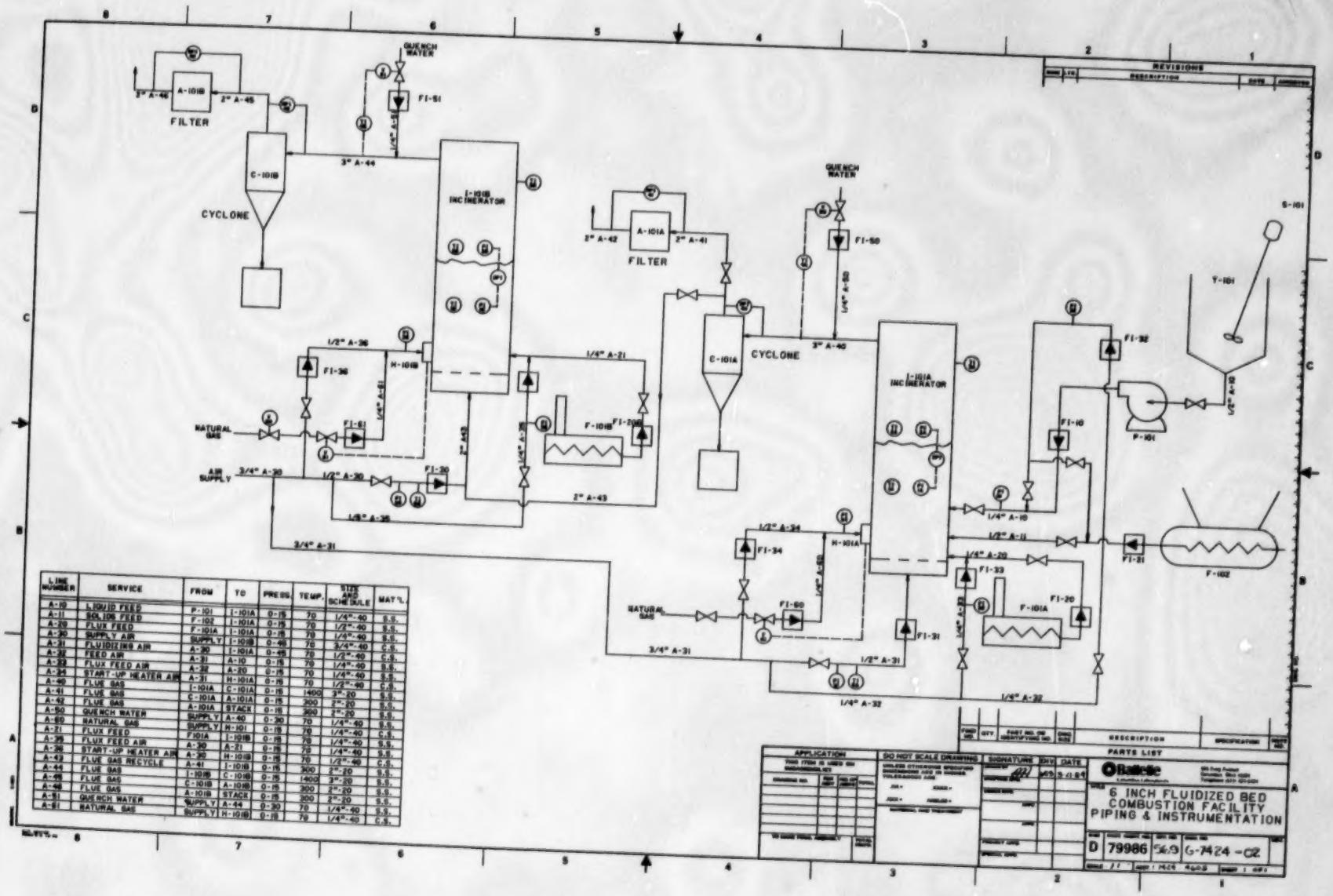
ITEM NO.	QTY	PART NO. OR IDENTIFYING NO.	MATL	DESCRIPTION	SPECIFICATION	NOTE NO.

APPLICATION	DO NOT SCALE DRAWING	SIGNATURE	DIV	DATE
THIS ITEM IS USED ON SUBASSEMBLIES	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ARE: .XX = ±.XXX .XXX = ±.XXXX			11/14/84

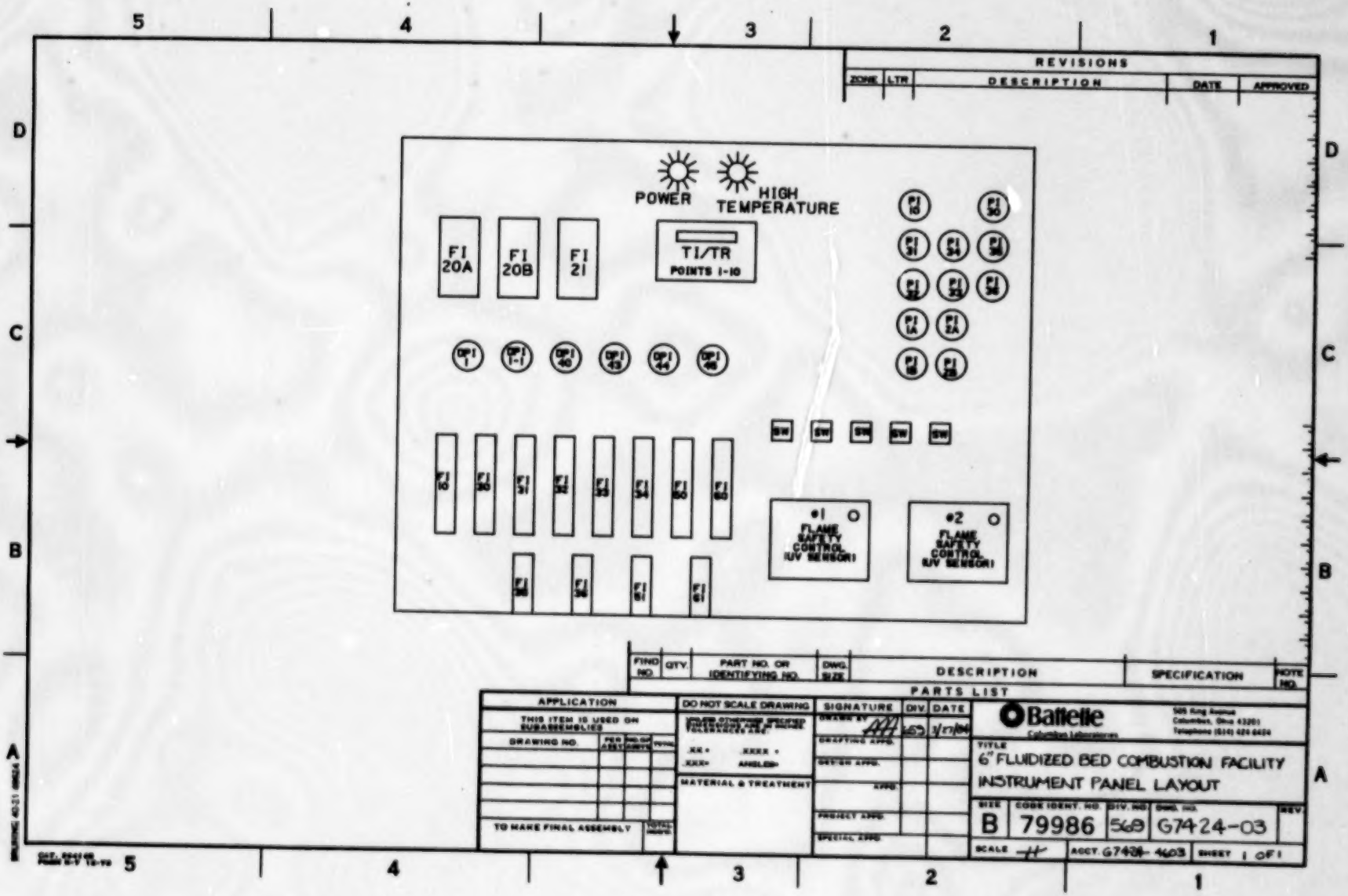
Battelle

6 INCH FLUIDIZED BED COMBUSTION FACILITY PROCESS FLOW DIAGRAM

SIZE	CAGE CODE NO.	DWG NO.	REV
D	79986	369	G7424-01



LINE NUMBER	SERVICE	FROM	TO	PRESS.	TEMP.	SIZE AND SCHEDULE	MAT'L
A-10	LIQUID FEED	P-101	I-101A	0-15	70	1/4"-40	S.S.
A-11	SOLIDS FEED	F-102	I-101A	0-15	70	1/4"-40	S.S.
A-20	FLUX FEED	F-101A	I-101A	0-15	70	1/4"-40	S.S.
A-30	SUPPLY AIR	SUPPLY	I-101B	0-15	70	1/4"-40	S.S.
A-31	FLUIDIZING AIR	SUPPLY	I-101B	0-45	70	3/4"-40	C.S.
A-32	FEED AIR	A-30	I-101A	0-45	70	1/2"-40	C.S.
A-33	FLUX FEED AIR	A-31	A-10	0-15	70	1/4"-40	S.S.
A-34	START-UP HEATER AIR	A-32	A-20	0-15	70	1/4"-40	S.S.
A-40	FLUE GAS	A-31	H-101A	0-15	70	1/4"-40	S.S.
A-41	FLUE GAS	I-101A	C-101A	0-15	1400	2"-20	C.S.
A-42	FLUE GAS	C-101A	A-101A	0-15	300	2"-20	S.S.
A-50	QUENCH WATER	A-101A	STACK	0-15	300	2"-20	S.S.
A-60	NATURAL GAS	SUPPLY	A-40	0-30	70	1/4"-40	S.S.
A-21	FLUX FEED	SUPPLY	H-101	0-15	70	1/4"-40	S.S.
A-35	FLUX FEED AIR	F-101A	I-101B	0-15	70	1/4"-40	S.S.
A-36	START-UP HEATER AIR	A-30	A-31	0-15	70	1/4"-40	S.S.
A-43	FLUE GAS RECYCLE	A-30	H-101B	0-15	70	1/2"-40	C.S.
A-44	FLUE GAS	A-41	I-101B	0-15	300	2"-20	S.S.
A-45	FLUE GAS	I-101B	C-101B	0-15	1400	2"-20	S.S.
A-46	FLUE GAS	C-101B	A-101B	0-15	300	2"-20	S.S.
A-51	QUENCH WATER	A-101B	STACK	0-15	300	2"-20	S.S.
A-61	NATURAL GAS	SUPPLY	A-44	0-30	70	1/4"-40	S.S.
		SUPPLY	H-101B	0-15	70	1/4"-40	C.S.



REVISIONS				
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FIND NO.	QTY.	PART NO. OR IDENTIFYING NO.	DWG. SIZE	DESCRIPTION	SPECIFICATION	NOTE NO.

PARTS LIST

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THIS ITEM IS USED ON SUBASSEMBLIES	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: .XX ± .XXXX ± .XXX ± ANGLES ±	DRAWN BY		
DRAWING NO. / PER ASSY / NO. OF ASSYS / TOTAL		CHECKING APPD.		
	MATERIAL & TREATMENT	DESIGN APPD.		
		APPD.		
		PROJECT APPD.		
TO MAKE FINAL ASSEMBLY / NOTES (MISC)		SPECIAL APPD.		

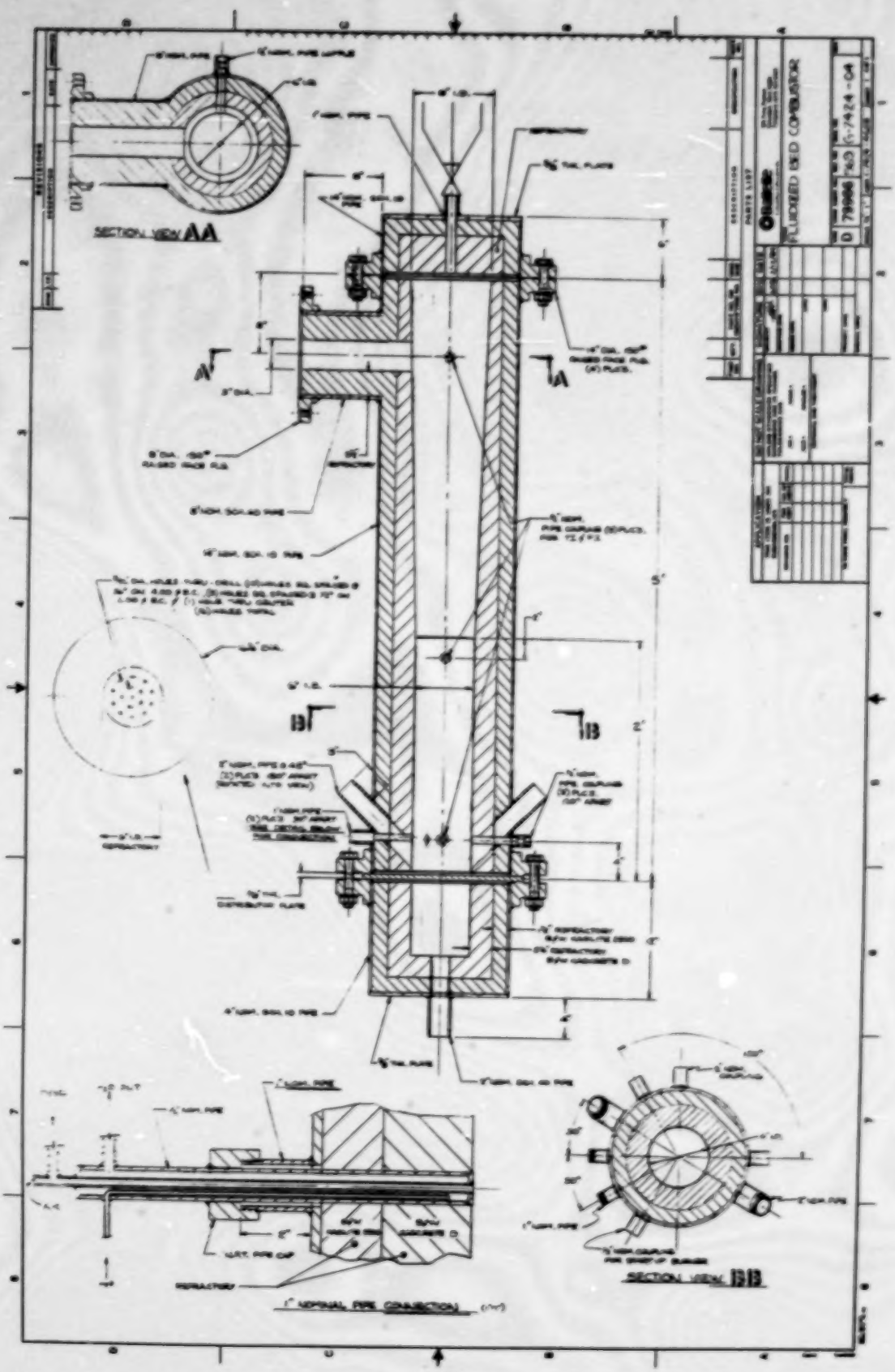
Battelle
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Telephone (614) 424-6424

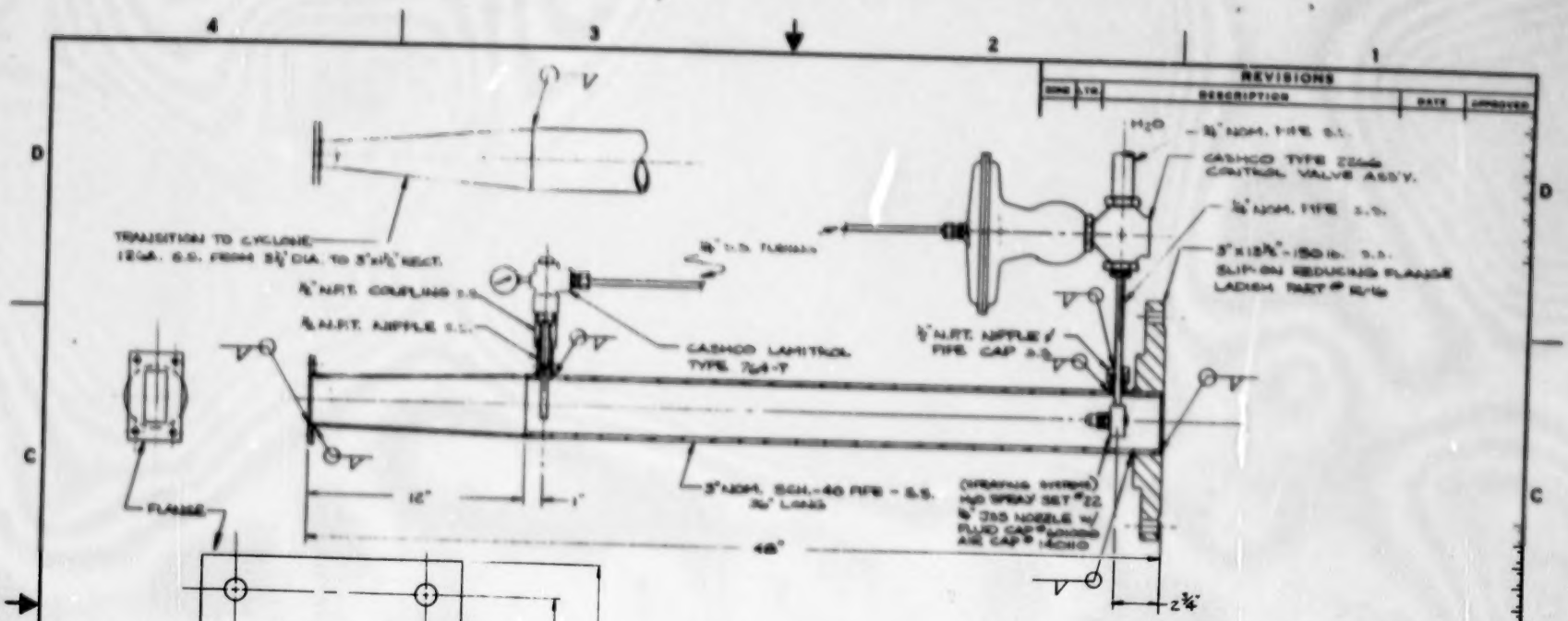
TITLE
6" FLUIDIZED BED COMBUSTION FACILITY
INSTRUMENT PANEL LAYOUT

SIZE	CODE IDENT. NO.	DIV. NO.	DWG. NO.	REV.
B	79986	569	G7424-03	

SCALE 1/4 | ACCT. G7424-403 | SHEET 1 OF 1

35


SECTION VIEW AA
SECTION VIEW BB
FLUIDIZED BED COMBUSTOR



FLANGE DETAIL (1'-1")

(1 REQ'D)

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

FIND NO.	QTY.	PART NO. OR IDENTIFYING NO.	DWG. SIZE	DESCRIPTION	SPECIFICATION	NOTE NO.

PARTS LIST

APPLICATION			
THIS ITEM IS USED ON SUBASSEMBLIES			
DRAWING NO.	PER ASSY	NO. OF ASSYS	TOTAL
TO MAKE FINAL ASSEMBLY			TOTAL REQ'D.

DO NOT SCALE DRAWING

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ARE:

XX ± .02 .XXX ±

.XXX ± ANGLES ±

MATERIAL AND TREATMENT

SIGNATURE	DIV.	DATE
DRAWN BY		5-23-84
DRAFTING APPD.		
DESIGN APPD.		
APPD.		
APPD.		
PROJECT APPD.		
SPECIAL APPD.		

Battelle
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Telephone (614) 424-6424

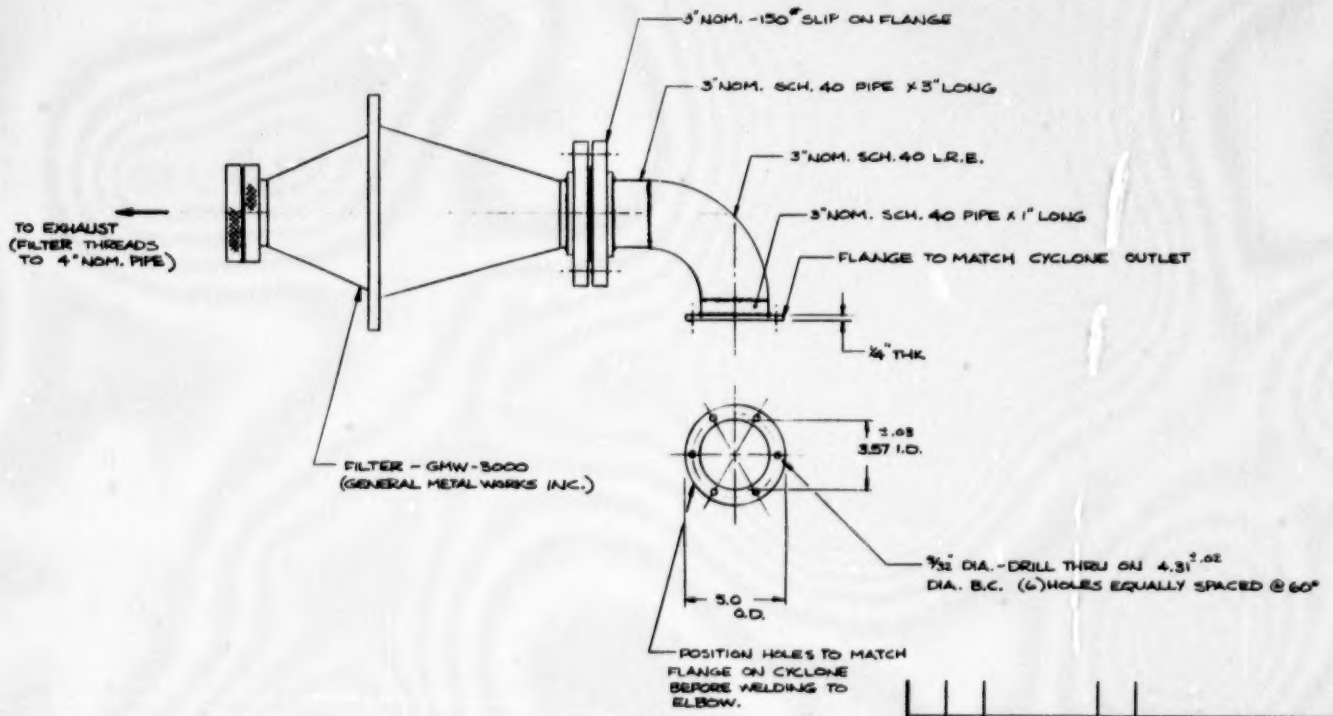
TITLE: WATER QUENCHED EXHAUST GAS DUCT

SIZE	CODE IDENT. NO.	DIV. NO.	DWG. NO.	REV.
C	79986	569	G-7424-05	

SCALE ¾"=1" | ACCT. G7424-4405 | SHEET 1 OF 1

DRG. NO.

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED


3" NOM. -150# SLIP ON FLANGE
3" NOM. SCH. 40 PIPE X 3" LONG
3" NOM. SCH. 40 L.R.E.
3" NOM. SCH. 40 PIPE X 1" LONG
FLANGE TO MATCH CYCLONE OUTLET
¼" THK.
TO EXHAUST (FILTER THREADS TO 4" NOM. PIPE)
FILTER - GMW-3000 (GENERAL METAL WORKS INC.)
2.03
3.57 I.D.
9/32" DIA. - DRILL THRU ON 4.31 +.02 DIA. B.C. (4) HOLES EQUALLY SPACED @ 60°
5.0 O.D.
POSITION HOLES TO MATCH FLANGE ON CYCLONE BEFORE WELDING TO ELBOW.

FIND NO.	QTY.	PART NO. OR IDENTIFYING NO.	DWG. SIZE	DESCRIPTION	SPECIFICATION	NOTE NO.

PARTS LIST

APPLICATION			
THIS ITEM IS USED ON SUBASSEMBLIES			
DRAWING NO.	PER ASSY	NO. OF ASSYS	TOTAL
TO MAKE FINAL ASSEMBLY			TOTAL REQ'D.

DO NOT SCALE DRAWING

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ARE:

.XX = ±.06 .XXX = ±.03

.XXX = ANGLES = ±1°

MATERIAL AND TREATMENT

SIGNATURE	DIV.	DATE
DRAWN BY	569	9-26-84
ENGINEERING APPR.		
DESIGN APPR.		
APPR.		
APPR.		
PROJECT APPR.		
SPECIAL APPR.		

Battelle
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Telephone (614) 424-6424

TITLE: FILTER ASSEMBLY

SIZE	CODE IDENT. NO.	DIV. NO.	DWG. NO.	REV.
C	79986	569	G-7424 -06	

SCALE 4"=1" | ASSY. G7424 - 4603 | SHEET 1 OF 1

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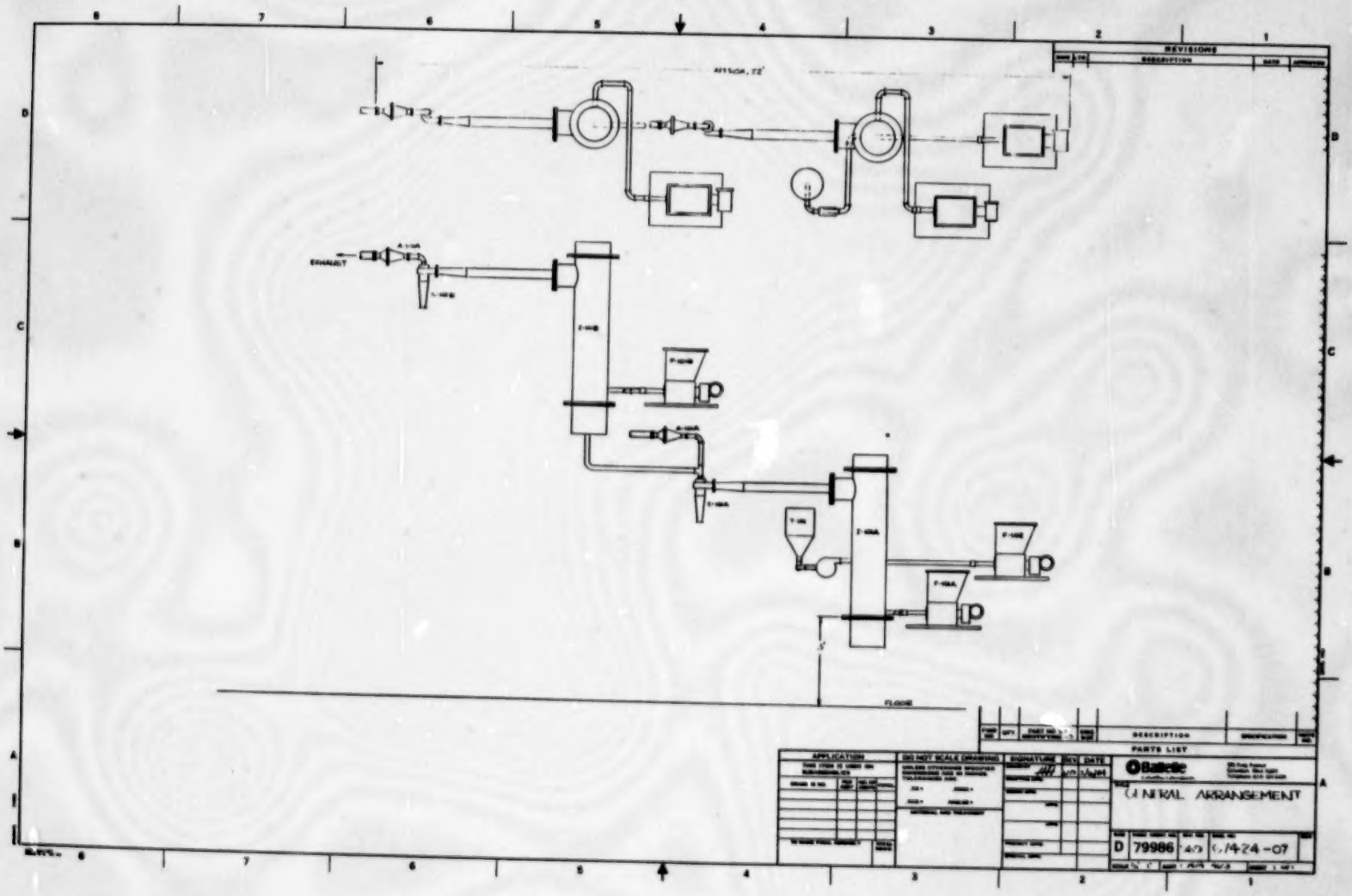
REVISIONS
PARTS LIST
GENERAL ARRANGEMENT
D
79986
0,14-24-07